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THE USAF ACADEMY FLYWHEEL-ELECTRIC CAR TECHNICAL REPORT

CAPTAIN ROBERT G. SCHWEIN, JR.

PROJECT 2303

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This is the second and final report on the USAF Academy Flywheel-Electric Car. The car is an operational test vehicle, not a prototype for a commercial car. It weighs 3100 pounds, carries 4 passengers, and cruises at 40 miles-per-hour for about 100 miles before recharging. Technical details are presented that will provide guidance to the reader who wishes to construct a similar vehicle.

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THE USAF ACADEMY FLYWHEEL-ELECTRIC CAR
TECHNICAL REPORT

By

Captain Robert G. Schwein; Jr.

December 1980

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INTRODUCTION

An electric car that uses a flywheel for short term energy storage is an efficient and economical means of transportation. The purpose of this report is to present the technical details of the operational flywheel-electric car at the USAF Academy. The car is not a prototype for a commercial vehicle, but it is an operational test platform for students and faculty to explore ideas that relate to energy storage, utilization, and control.

The flywheel-electric car is an electric car (electric motor and batteries) that has two additional very important components, a transmission and a flywheel. When this electric car is slowed down or stopped, the car's kinetic energy is stored as rotational energy in the flywheel. When the car accelerates the kinetic energy comes from the stored energy in the flywheel. The transmission transports the energy from the car to the flywheel and vice-versa as the driving conditions dictate.

The scope of this report is limited to the technical details of the flywheel electric car. Actual component values are presented when noise or other invasive anomalies required careful design. Specifications and measurements are not given in areas of design that allowed a great deal of latitude. This report does not review current electric vehicle (without flywheels) limitations, design considerations of the flywheel electric car, the rational behind the design choices made, or the theory in the operation of the transmission and flywheel. A complete coverage of the above and more is found in

The USAF Academy Flywheel-
Electric Car Preliminary Design Report
FJSRL Technical Report -79-0006; May 1979.
DAVID D. RATCLIFF

Because the Preliminary Design Report has already done so, this report makes no attempt to pull the many systems on the car together into a coherent operational picture. It would be best for the reader to read the Preliminary Design Report before studying the details contained in this report.

When driving the car the first impressions were very good. The car can accelerate from 0 to 40MPH in 7 seconds and can obtain minimum stopping distance by keeping the rear wheels in an incipient skid. The excellent responsiveness can be attributed to the transmission being able to transfer energy at a very high rate to or from the flywheel. Because of high mechanical stresses that can be placed on the components within the transmission, great care must be taken in material selection and component fabrication. No road test has been made that would simulate city or open road driving. This and other tests to measure losses and efficiencies constitute the project phase that is just being entered.

This report first presents the placement of major components on the car chassis, then the details of the major mechanical and electrical systems, and ends with the results of a preliminary energy consumption test.

Top view of Flywheel Electric Car; Fig 1

This is a top view of the car illustrating major component placement. The total weight of the car is 3100 pounds and is evenly distributed over the 4 wheels.

Battery weight........	1100 pounds	35% of total weight
Flywheel...............	200	6%
Electric motor and transmission.......	300	11%
Chassis, frame, etc...	1500	48%
TOTAL	3100 pounds	100%

[1] Forward battery bay (9 batteries)

[2] Middle battery bays (5 batteries)

[3] Rear battery bay (3 batteries)

[4] Instrument dashboard

[5] Drivers seat

[6] Electric drive motor

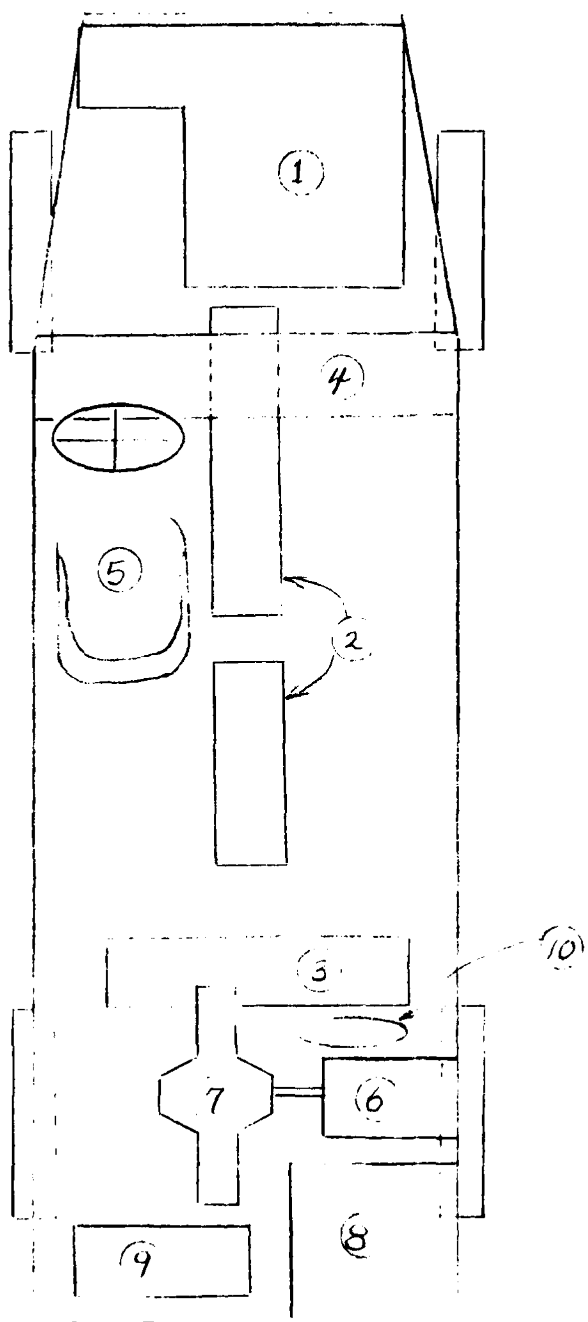
[7] Flywheel

[8] Electronics bay

[9] Transmission

[10] One ohm, 10 kilowatt armature protection resistor

FIG 1; TOP VIEW OF FLYWHEEL ELECTRIC CAR



Continuously Variable Transmission, Fig 2

The purpose of the transmission is threefold. First it is to control the rate the stored flywheel energy is transferred to accelerate the car and vice-versa. Second it is a torque amplifier for the eight-and-a-half HP electric motor when driving the car at constant speed. Third the driver (or automatic controller) will set the transmission to keep the electric motor running within its efficient range of 3200 to 5000 RPM regardless of the car's forward speed.

The view of the transmission (Fig 2) is as if you were standing behind the car looking forward.

[1] Transmission shifting lever

[2] Transmission shifting lever pivot point

[3] This side of variable diameter pulleys is rigidly secured to their respective shafts.

[4] This side of variable diameter pulleys can slide along splines on their respective shafts.

[5] Shaft support bearings

[6] This shaft is splined into sun gear in the planetary gear system

[7] This shaft is splined into the planet carrier in the planetary gear system

[8] This is the ring gear drive pulley (144 teeth)

[9] Planetary gear system

[10] Sun gear drive pulley (80 teeth). Power is routed from this pulley through the shaft, through the variable diameter pulleys, then through the shaft that is splined into the sun gear [6].

[11] Drive chain sprocket (30 teeth). The sprocket on rear axle has 60 teeth.

[12] Flywheel shaft pulley (38 teeth)

[13] Flywheel

[14] Ribbed timing belt

[15] Rubber belt on variable diameter pulleys.

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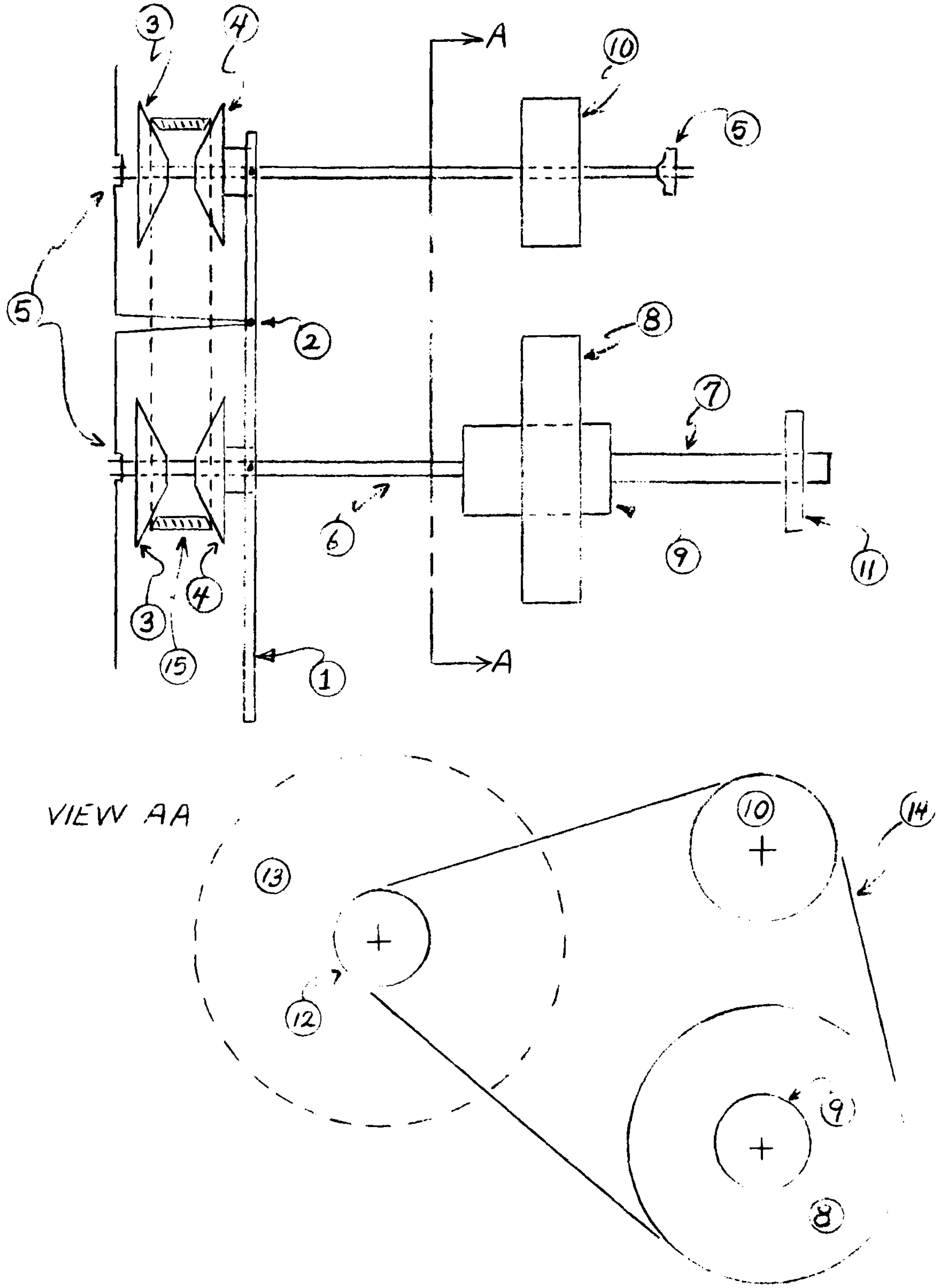
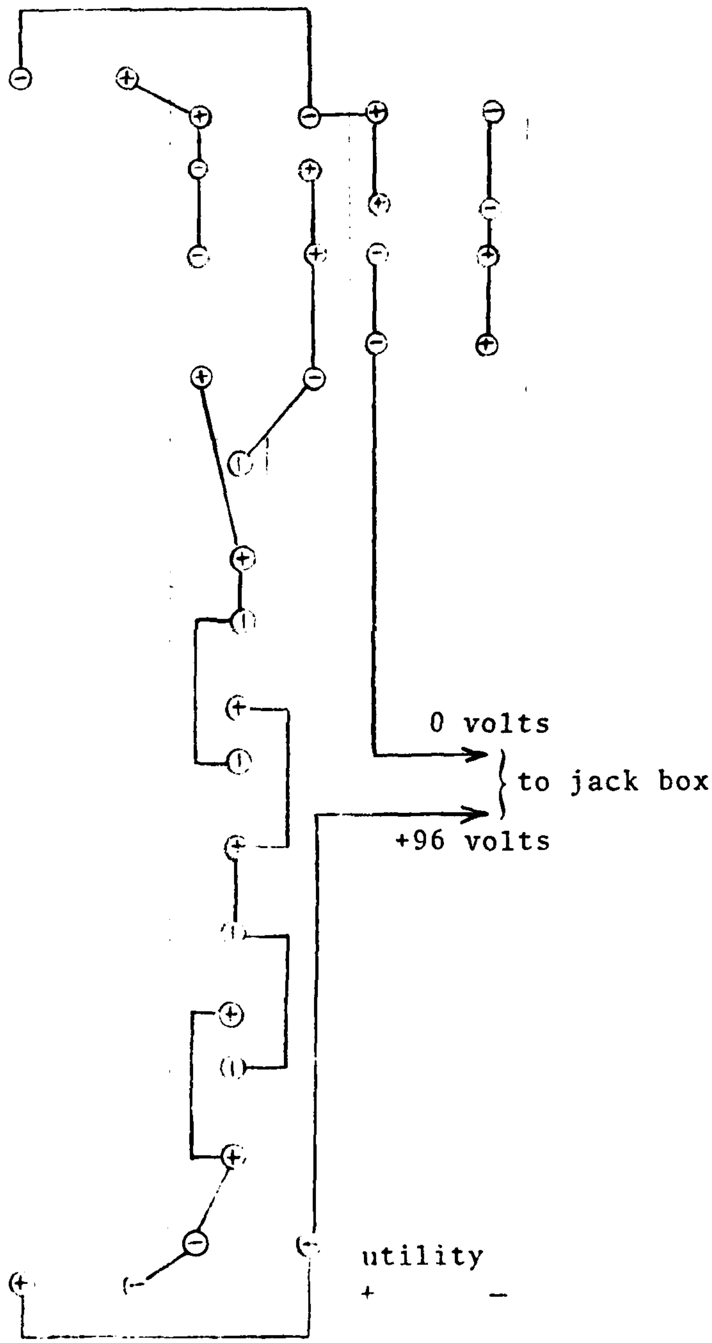
FIG 2; CONTINUOUSLY VARIABLE TRANSMISSION



Battery Wiring for Main Drive Motor; Fig 3

This figure shows how 16 of the 17 lead-acid 12 volt batteries are wired to produce the 96 volts for the drive motor. The 17th battery is a utility battery that could be used to supply power to 12 volt systems such as headlights etc. The output leads of the 96 volt battery array are terminated with two heavy duty jacks enclosed in a box sitting on top of the rear battery bay. To charge the batteries, the operator must pull the electric motor plugs from the jack box and plug in the battery charger. When the car is not being driven or the batteries not being charged then nothing is plugged into the jack box. This partially isolates the batteries from everything else in the car. The only other plug that needs to be removed to completely isolate the batteries is the electronics power plug described in figures 4 and 5.

FIG 3; BATTERY WIRING FOR MAIN DRIVE MOTOR

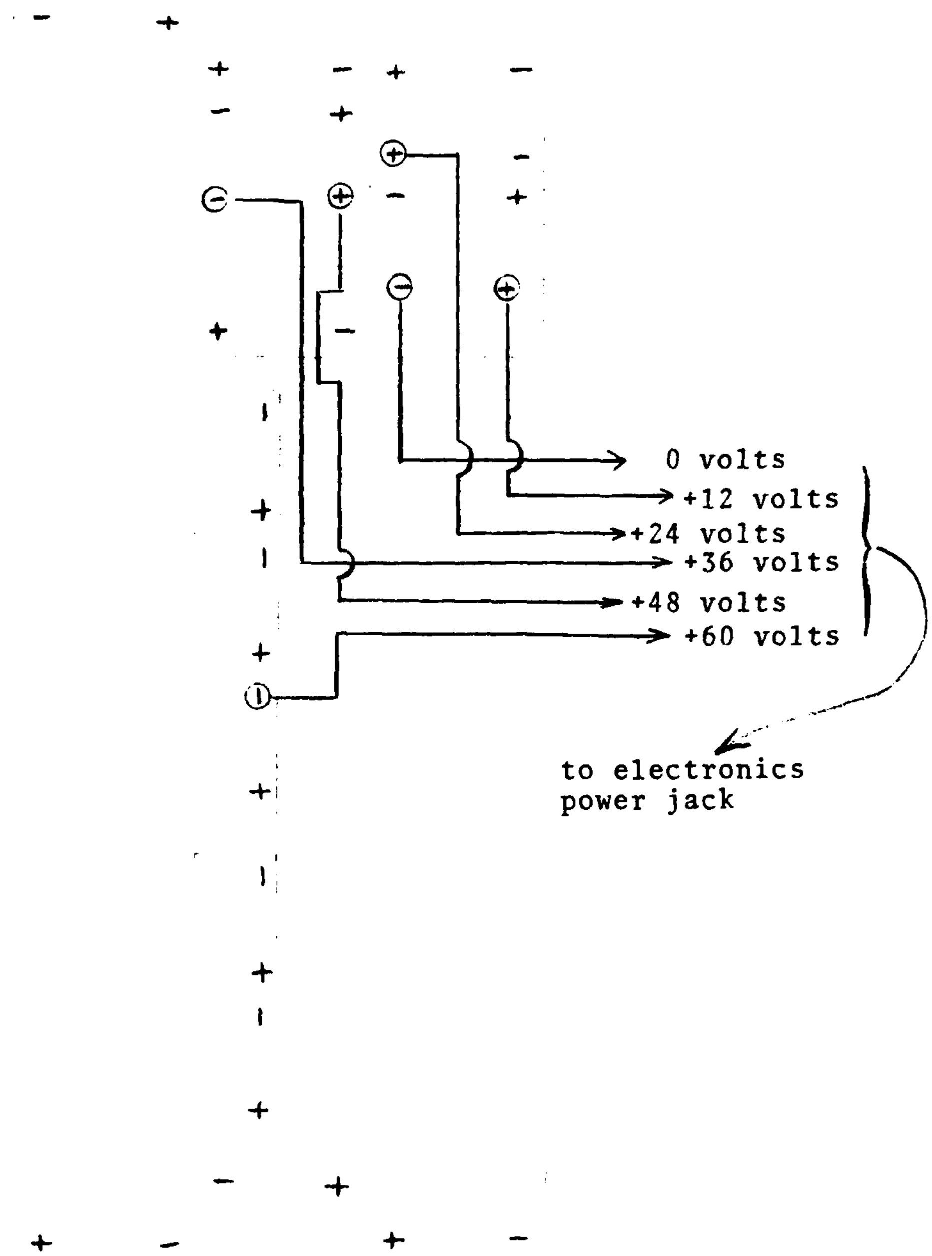


Multiple Voltage Taps on Main Battery Array; Fig 4

This figure illustrates which batteries are used to supply the voltage requirements of the on board electronics. The six output wires on this figure are terminated at a jack secured to the electronics bay platform. As mentioned earlier (fig 3), the plug to this jack must be pulled if you wish to completely isolate the batteries.

When these power leads are plugged into the car for driving purposes the power is routed to two places: first directly to the cooling fans and power relays that require 12 and 24 volts (fig 11), and second, to the electronics power supply (figs 5 & 6). The power supply adjusts the battery voltages to more suitable values for the control and monitoring electronics.

FIG 4; MULTIPLE VOLTAGE TAPS ON MAIN BATTERY ARRAY

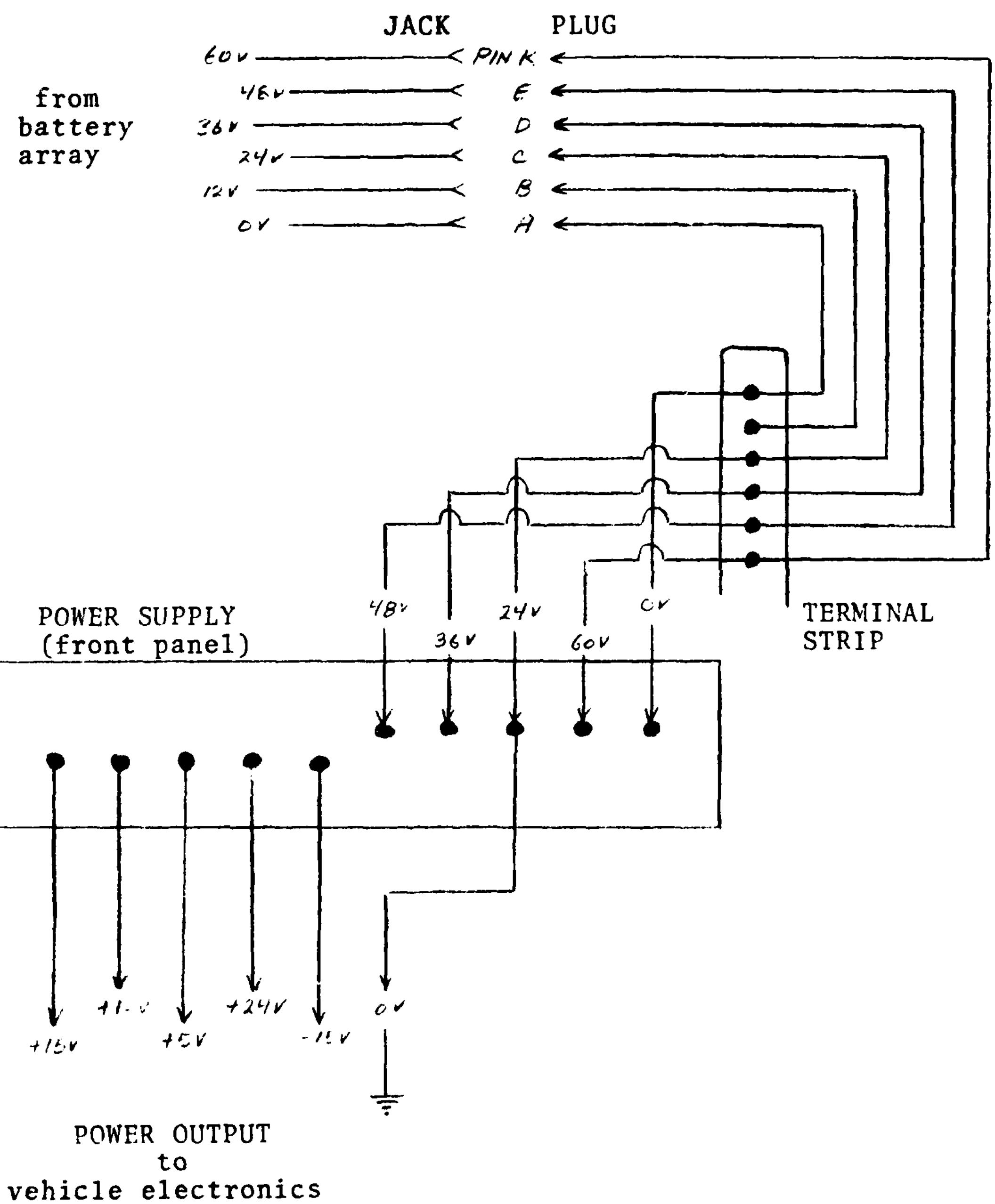


Electronics Power Supply External Connections; Fig 5

This figure shows how the power is brought from the batteries (fig 4) to the front panel of the electronics power supply. The electronics power jack, terminal strip, and power supply are in the electronics bay in the right rear of the car (fig 1). It should be noted that except for the main DC motor, all equipment on the car is ultimately wired to a terminal on the terminal strip. Some equipment is powered from the power supply, while the rest is powered directly from the terminal strip.

The power supply requires 5 input voltages and has 6 output voltages. All electrical equipment floats, there is no electrical connection to the car frame. The zero volt reference for the electronics is the 24 volt battery level as illustrated in this and next figure.

FIG 5; ELECTRONICS POWER SIPPLY EXTERNAL CONNECTIONS



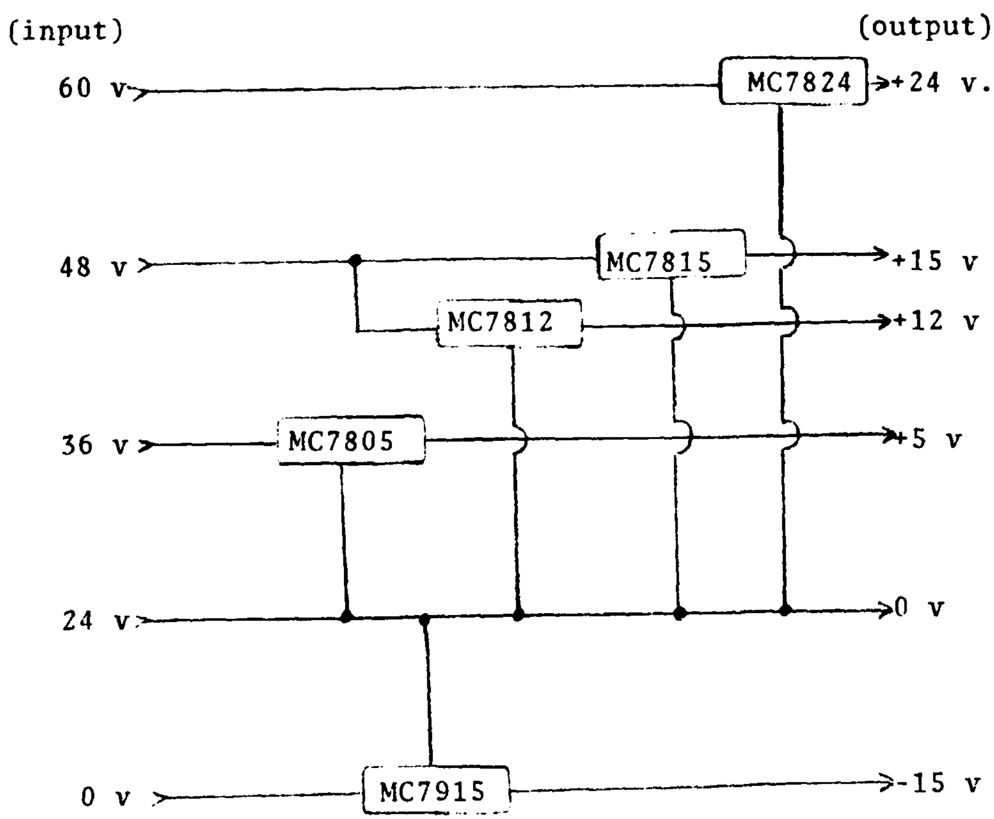
Power Supply Schematic; Fig 6

The power supply (front panel shown in fig 5) is secured to the electronics bay platform. Three terminal regulators, 78XX and 79XX, in TO-3 cans heat sunk to deliver 3 amperes continuous, are used to derive the necessary voltage levels. The MC7824 is an exception; it is a TO-220 case and its purpose is to deliver current to the armature of the transmission shifting drive motor. The +/- 15 volts are used for OP-AMPS and servo motor fields. The +5 and +12 volts are intended for microprocessor uses. A detailed schematic of one of each type of regulator used is at the right side of the figure.

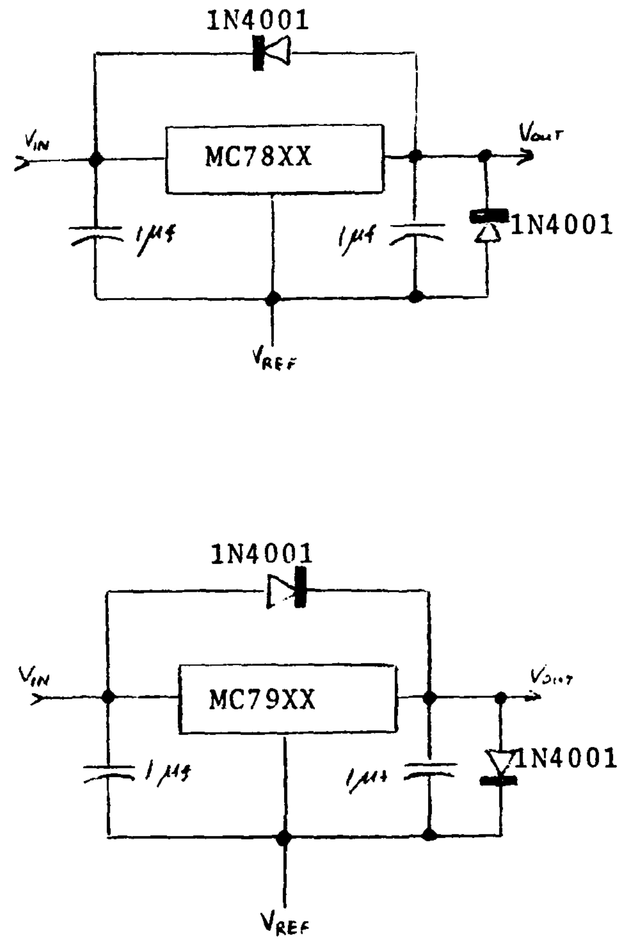
Wires from the power supply to all equipment are shielded or twisted pairs. Noise or transients have been no problem in any equipment on the car. When battery voltage levels drop to 60% of their 12 volt rated value (during main motor start up) the power supply output remains steady at designed levels and there is no loss of control in any equipment.

FIG 6; POWER SUPPLY SCHEMATIC

POWER SUPPLY



DETAIL of 3 TERMINAL REGULATOR CIRCUITS

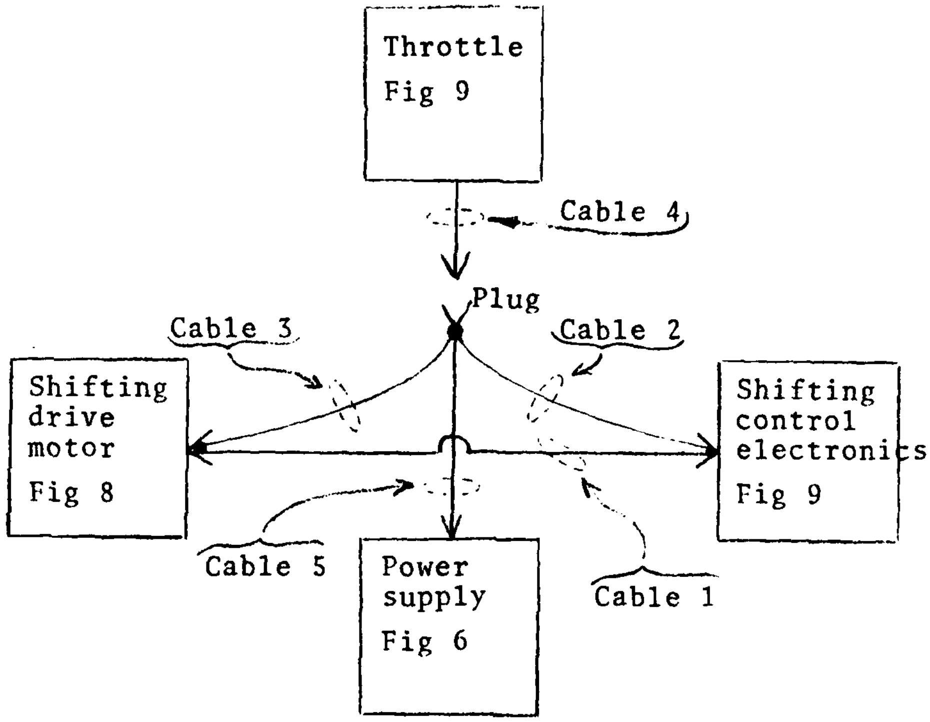


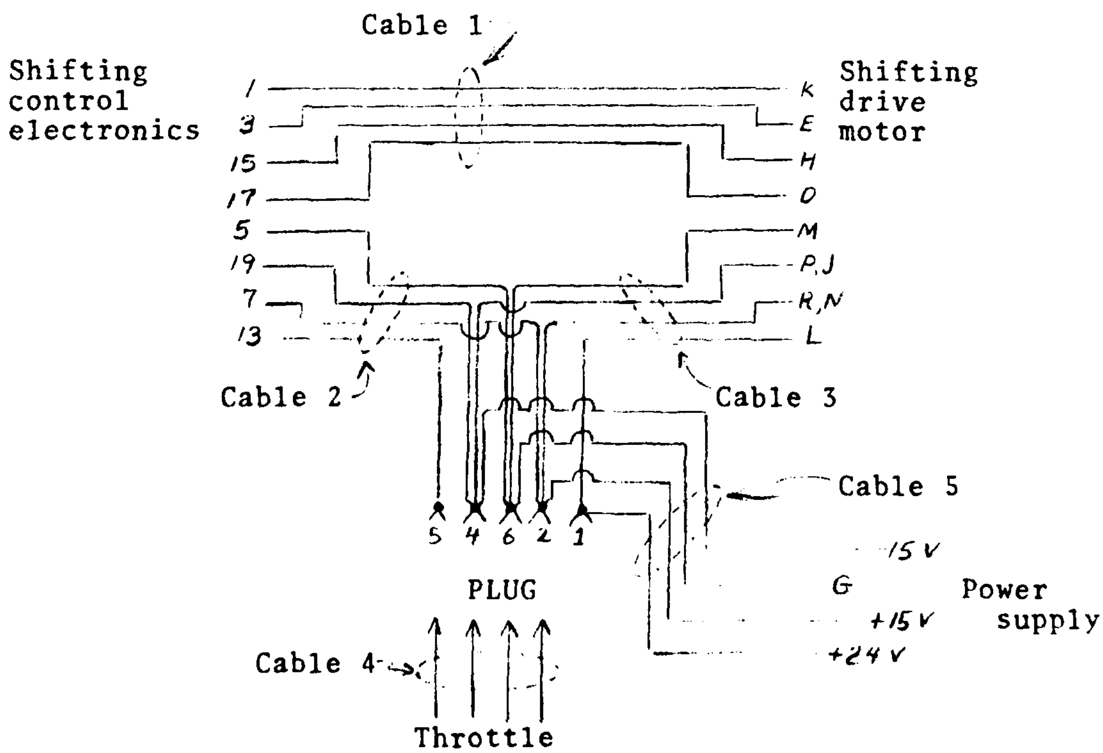
Throttle/Shifting Control Systems Diagram; Fig 7

There are four major systems used to shift the transmission and therefore control the car speed. The throttle (in fig 9) is located on the middle battery bay next to the driver. The shifting control electronics package (fig 9) and power supply (fig 6) are secured to the electronics bay platform. The shifting drive motor with electronics (fig 8) is mounted on the car frame under the transmission. These four systems and their electrical interconnections are depicted at the top of this figure (7).

The 5 cables that interconnect the four systems are shown in detail at the bottom of the page. Each cable is a shielded bundle of four wires. The pin numbers corresponding to the plug for each system are explicitly shown.

FIG 7; THROTTLE/SHIFTING CONTROL SYSTEMS DIAGRAM

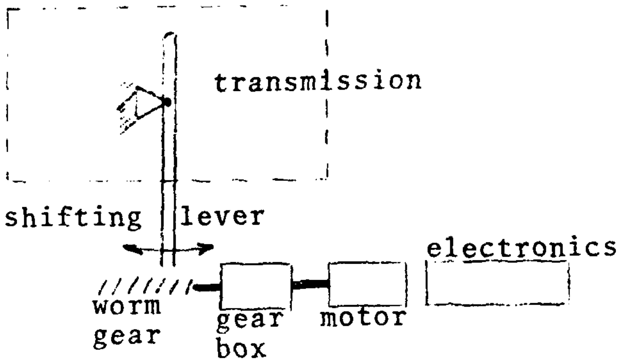




Shifting Drive Motor/Electronics; Fig 8

In the upper left of this figure you note that the motor drives a gear train which inturn drives a worm gear. The transmission shifting lever (fig 2) is geared to the worm gear. When the drive motor is on, the lever will swing in a direction that depends on the direction of rotation of the drive motor.

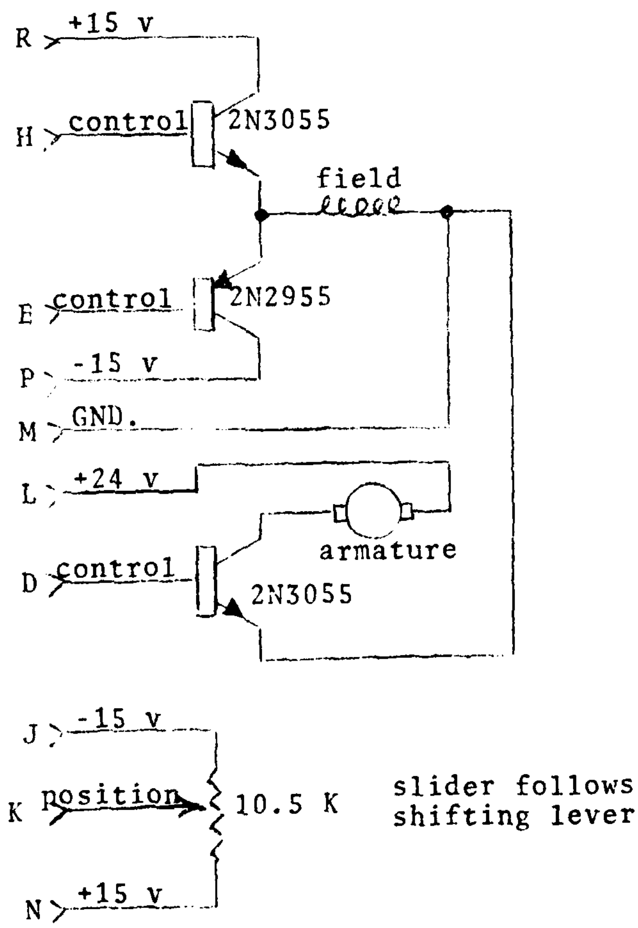
The electronics that are mounted on the frame with the shifting motor are shown schematically at the bottom of this figure. The direction the motor turns is controlled by connecting the field to +15 or -15 volts using the NPN or PNP transistors. The directional control signal from the shifting control electronics (fig 9) is on pins H and E. The position of the shifting lever arm is electrically determined by a variable resistor. The slider is attached to the lever thus when the lever moves the potential on the slider is changed.



secured to car frame
underneath transmission

FIG 8

SHIFTING DRIVE MOTOR
and ELECTRONICS



Shifting Control Electronics Package; Fig 9

The purpose of the Shifting Control Electronics Package is twofold. First it determines if there is a difference between where the driver has set the throttle and where the transmission shifting lever is supposed to be. Secondly, if there is a difference, then it will drive the shifting motor (fig 8) to move the shifting lever to its proper position.

Amplifier A is the difference amplifier, its output voltage magnitude is the measure of how large of a difference there is between the shifting lever present position and proper position (the latter is determined by the throttle). The sign of Amp A output voltage tells if the lever has gone beyond or not far enough to reach the proper position.

Amplifier B uses the sign information to determine the direction the shifting lever drive motor will have to move the shifting lever to position it where the throttle demands it to be.

Amplifiers C and D use the magnitude information to determine how fast the shifting lever drive motor should move the shifting lever to the proper position, the larger the error then the faster the lever is moved.

The shifting lever drive motor is a fractional horsepower shunt wound DC motor. Its direction of rotation, determined by Amp B, is controlled by applying +/-15 volts to the field coils (fig 8). The rotational speed, determined by Amps C and D, is controlled by the voltage magnitude applied to the armature. Amplifier C is an absolute value amplifier whose purpose is to remove sign information but retain the magnitude of the error information. Amplifier D's output range is from -1 volt to +13 volts. The -1 to 0 volt range is a dead band to ensure the shifting lever drive motor does not continually "hunt" when the shifting lever is in the proper position.

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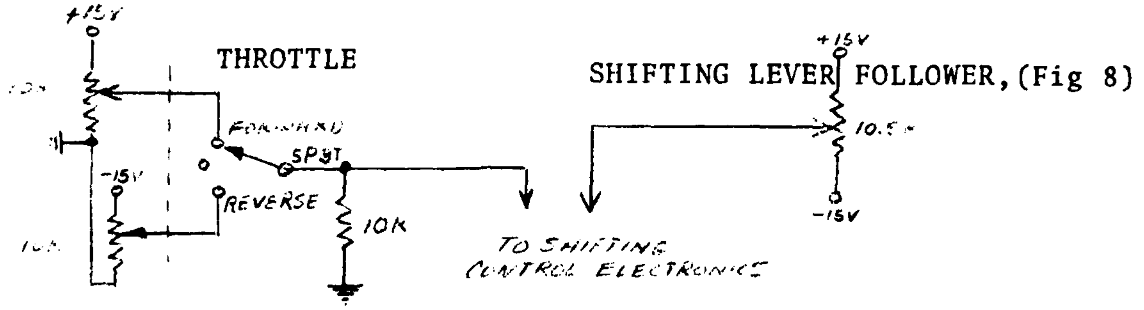
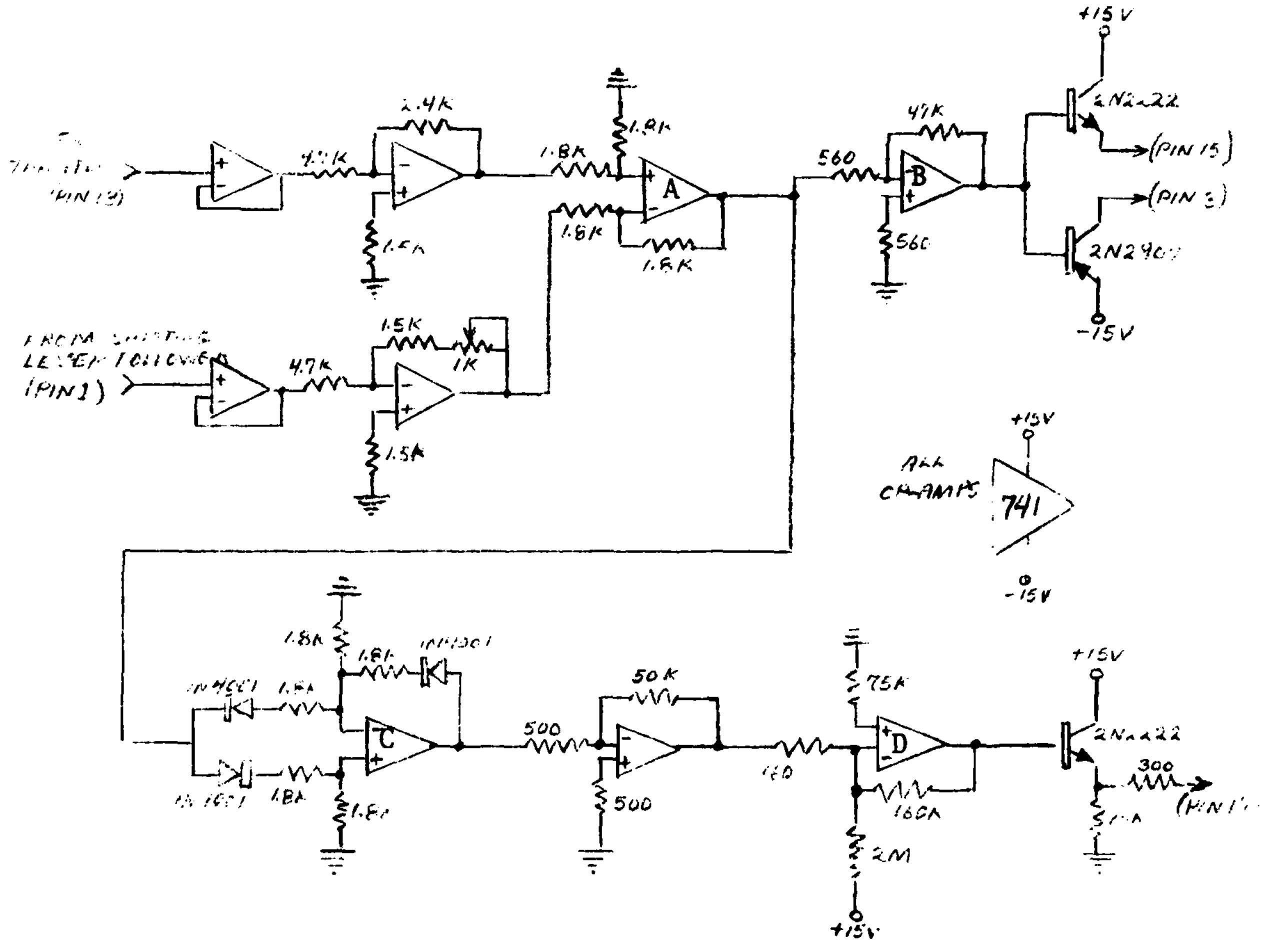


FIG 9; SHIFTING CONTROL ELECTRONICS

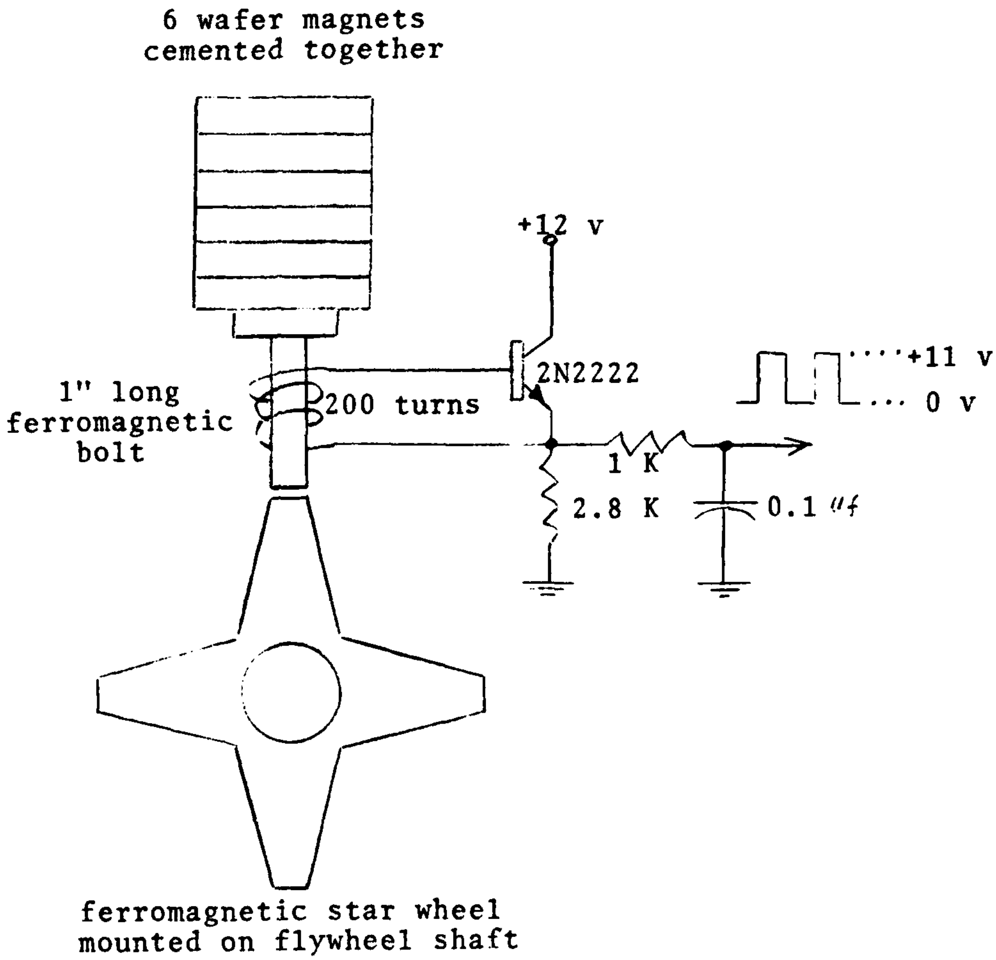


Tachometer Sensor; Fig 10

The tachometer on the dashboard of the car is a commercial unit bought at a local auto parts store. It is used to measure the Electric motor RPM. Since tachometers for gas auto engines require electrical pulses (4 pulses constitute 1 revolution), this figure shows how the necessary pulses are generated.

A 4 pointed star wheel, measuring about 5 inches in diameter, is mounted concentrically on the electric motor/flywheel shaft. A one-inch-long bolt with six wafer magnets cemented to its head is secured to the car frame. As the star wheel turns, each point brushes past the tail of the bolt with a clearance of about 1 millimeter. The bolt, which has about 200 turns of #32 wire wrapped around its shaft, and the star wheel are made out of ferromagnetic metal. As a tip of the star passes the bolt, magnetic field lines around the bolt change position thus inducing a current pulse in the wire winding. This current pulse is sensed and amplified by the amplifier mounted near the bolt. The sensor and amplifier are illustrated in this figure.

FIG 10; TACHOMETER SENSOR



Main Drive Motor Control; Fig 11

This figure shows everything there is to turning the eight-HP electric motor on and off, and controlling its speed. Switches S1 and S2 are mounted on the dashboard next to the driver; the field strength resistor box sits on top of the center battery bay next to the driver; the relays R1 and R2 are mounted in the electronics bay. S1 when turned on will close R1, likewise S2 will close R2 which is a shunt around the 1 ohm armature protection resistor. The 0 and 96 volts come directly from the batteries (fig 3).

NORMAL TURN ON

1] Turn off S1 & S2

2] Plug in battery power leads on battery connection box

3] Plug in electronics power jack on electronics bay

4] Turn on S1

5] At 1200 RPM turn on S2

6] Set desired RPM with field resistors

NORMAL TURN OFF

1] Set field strength to maximum with field resistors

2] Turn off S2

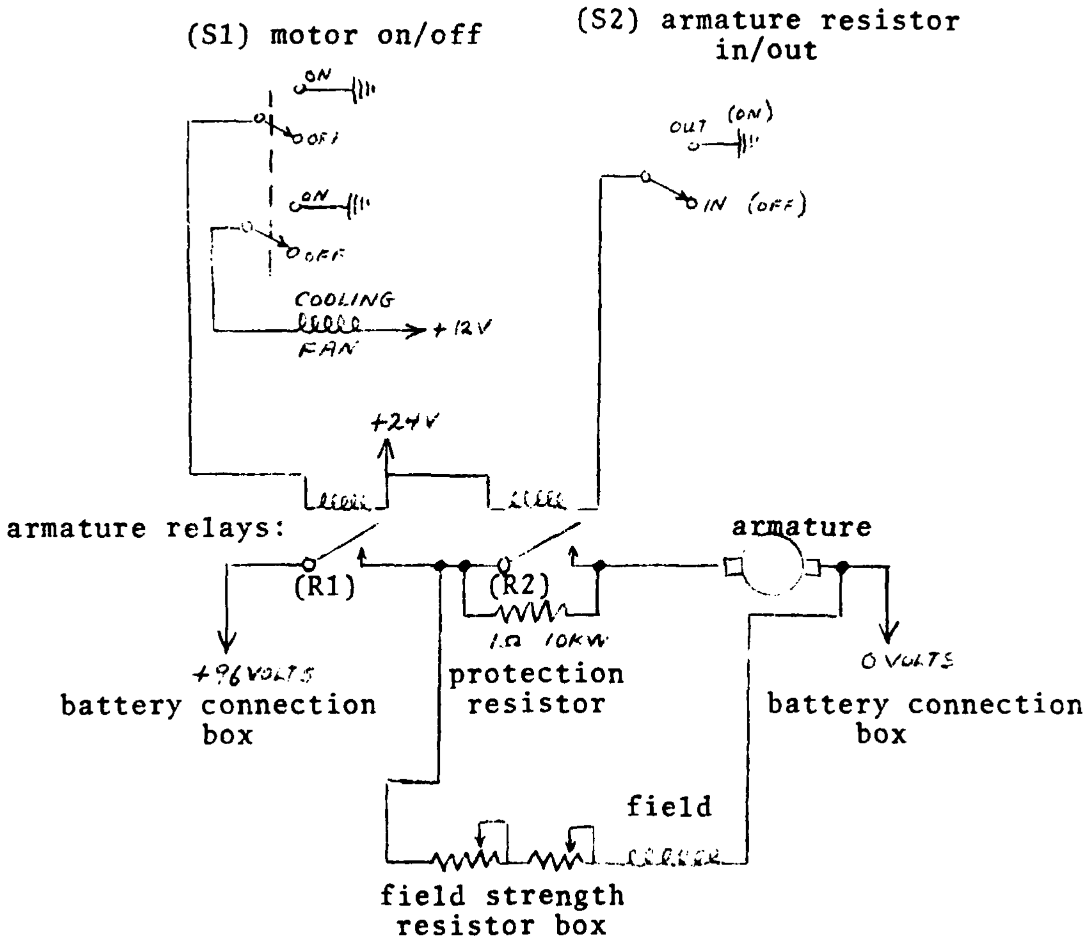
3] Turn off S1

4] Unplug battery and electronics power plugs

EMERGENCY OFF

1] Turn off S1

FIG 11; MAIN DRIVE MOTOR CONTROL

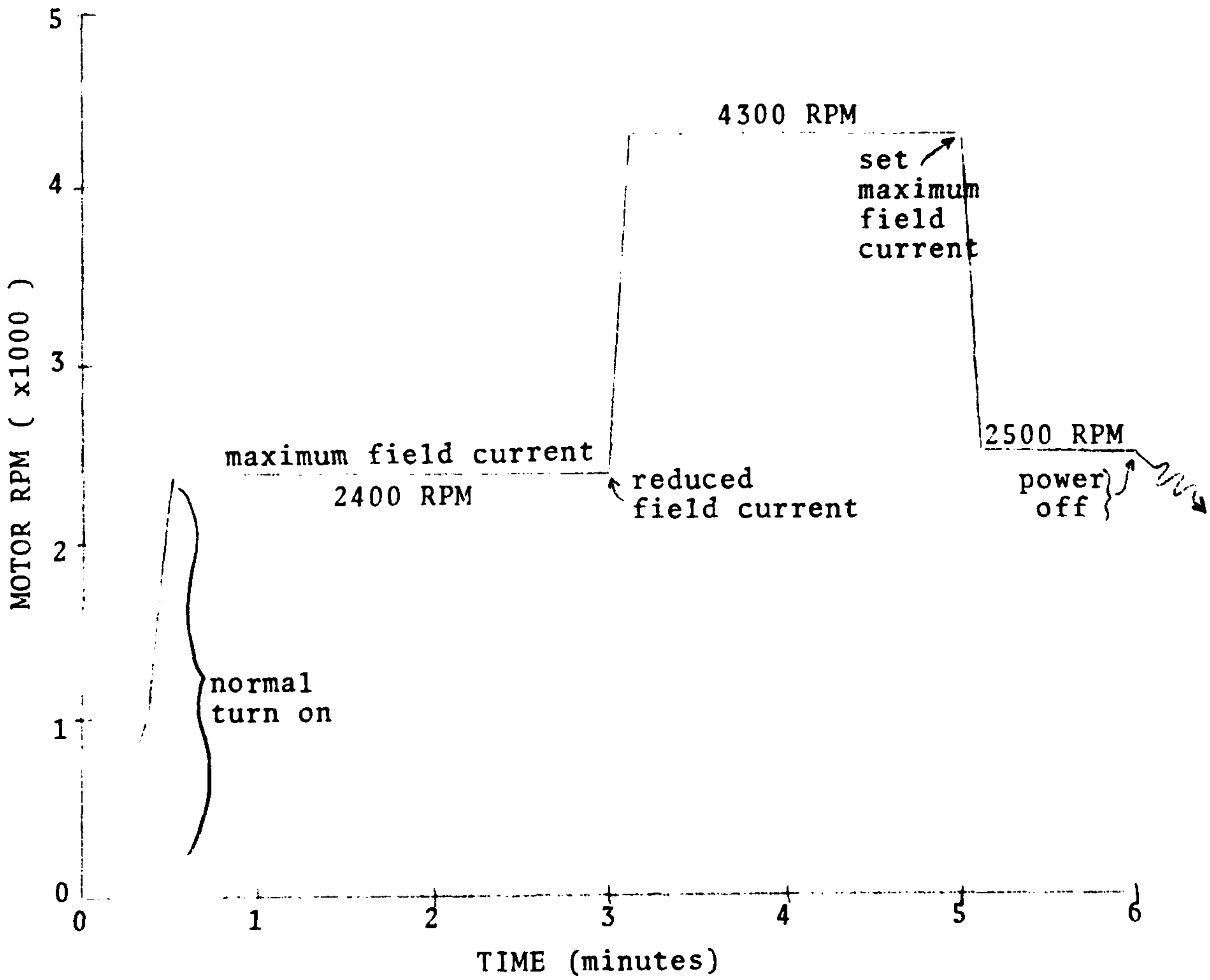


Energy Consumption Test; Fig 12

The test and measured results are presented without any attempt to draw conclusions. The test was performed over a 6 minute time interval and was needed to determine if any gross losses were present within the vehicle systems. The motor was turned on, 30 seconds later RPM stabilized at 2400 RPM. The motor (connected to flywheel and transmission) ran at this RPM for 2.5 minutes at which time the field current was reduced to obtain 4300 RPM. This high RPM was maintained for 2 minutes then the field current was set to maximum again and RPM stabilized at 2500 RPM for a 1 minute time interval. At this time the motor was turned off. The transmission was in neutral (car not moving) during the test.

Measurement of battery electrolyte specific gravity before and after the test showed that 2.9% (+/- 0.5%) of the stored energy was consumed.

FIG 12; ENERGY CONSUMPTION TEST



RESULTS: 2.9% (+/-0.5%) of battery energy consumed